Spin-glass phases in quantum simulators: projection quantum Monte Carlo studies

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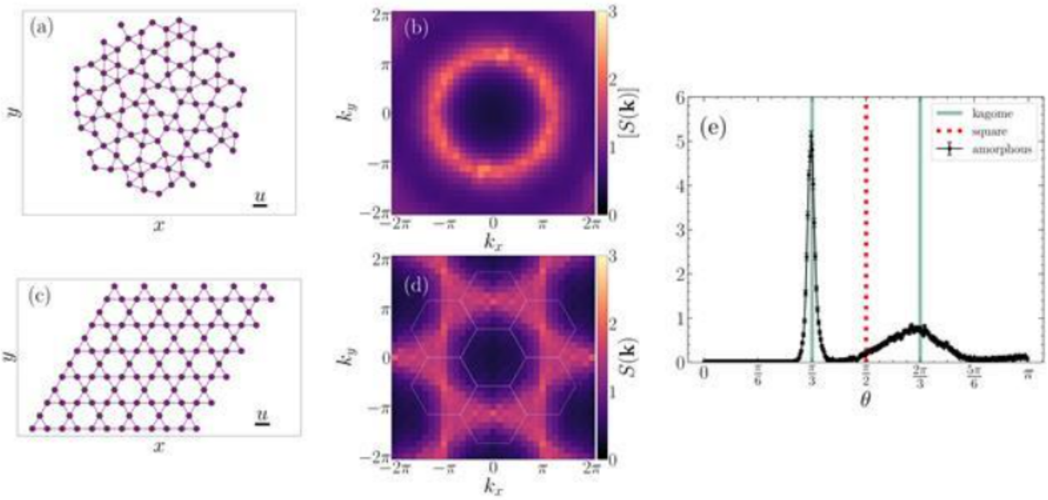
Various experimental platforms, including Rydberg atoms trapped via optical tweezers, quantum annealers built with superconducting qubits, and trapped ions, are emerging as ideal quantum simulators of complex phenomena due to disorder and strong correlations. Here, we employ projection quantum Monte Carlo (PQMC) algorithms to investigate the possible occurrence of spin-glass quantum phase transitions in the ground-state of these systems. The role of so-called neural quantum states as effective variational ansatzes, useful to boost the performance of PQMC simulations, is discussed. Then, we show how to determine the replica overlap and, chiefly, the energy gap, with PQMC algorithms.

First, we make comparisons with recent path-integral Monte Carlo (PIMC) results [Nature 631, 749 (2024)] for the spin-glass transition and the energy-gap scaling of the 2D Edwards-Anderson model [1]. The super-algebraic scaling of the symmetry unrestricted gap, previously predicted by the PIMC simulations in the case of binary couplings, is confirmed here considering Gaussian couplings, pointing to a universal feature of 2D quantum spin glasses [2]. In contrast, for the quantum Sherrington-Kirkpatrick Hamiltonian, a benign power-law scaling is found, indicating a polynomial computational complexity of quantum annealing for dense quadratic combinatorial optimization problems. For Rydberg-atom setups, it is predicted that a spin-glass quantum phase transition could be observed by arranging the optical tweezers in an engineered amorphous configuration [3]. Specifically, this configuration locally resembles the connectivity of the kagome lattice, but it lacks long-range periodicity. If time permits, we will discuss how quantum annealers and classical autoregressive neural networks can be combined to accelerate Monte Carlo simulations of classical spin glasses [4] in a hybrid quantum-classical approach [5].



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